AN INVESTIGATION OF THE EFFECTS OF VARIATIONS IN AGGREGATE GRADATION UPON THE STRENGTH AND ABSORPTION OF ZERO SLUMP CONCRETE MADE FROM AGGREGATES OF THE SAME FINENESS MODULUS

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AN INVESTIGATION OF THE EFFECTS OF VARIATIONS IN AGGREGATE GRADATION UPON THE STRENGTH AND ABSORPTION OF ZERO SLUMP CONCRETE MADE FROM AGGREGATES OF THE SAME FINENESS MODULUS

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ABSTRACT

The design of concrete mixes of zero slump is of great importance to the concrete products industry. At the present time, mix design in the field, as practiced by the concrete products manufacturer, is a trial and error proposition. The water-cement ratio law and other information developed by Duff A. Abrams at the Structural Materials Research Laboratory of the Lewis Institute combined with past practical experience of the operator are used as guides in the design.

In zero slump concrete, the total water content is an extremely critical factor; consequently it was felt that the aggregate gradation was probably of much greater importance in the design of zero slump mixes than in plastic mixes. From the outset, it was apparent that a complete investigation of the effects of aggregate gradation would be beyond the scope of this thesis because of time limitations. Also, before engaging in a detailed study, it was felt that a number of preliminary investigations should be conducted to determine if the effect of variations in the gradation of aggregate is of sufficient magnitude to warrant such a project.

In an effort to determine the effect of different gradations upon the strength and absorption of zero slump concrete, a number of gradations with the same fineness modulus were designed. Cylinders were molded from concrete mixes in which the aggregate had these gradations. Aggregate cement ratios of

three to one, four to one, and five to one, were used.

After curing for twenty eight days, these cylinders were tested in direct compression and also for absorption. Appropriate curves were developed. From these curves it is apparent that concrete mixes made with aggregates of different gradation, but with the same fineness modulus, will show considerable variation in the properties of compressive strength, absorption and unit weight. Definite relationships between these properties and the gradation of the aggregate appear to exist although they cannot be defined as a result of these tests.

Insufficient data was collected during this investigation to allow for the formulation of a theory of aggregate gradation design, but it is believed that a more detailed investigation is justified and that further research will make such a design theory possible, resulting in considerable savings for the concrete products industry.

CHAPTER I

INTRODUCTION

In recent times the manufacture of concrete block and other concrete products has become an extensive and rapidly expanding industry, with concrete masonry units today accounting for seventy per cent of all total wall volume. (1)[1] In spite of this expansion, very little is known about the properties of the industry's basic material--plain concrete of zero slump.

The design criterion for the proportioning of zero slump mixes used by the industry at the present time is based largely upon the general methods of concrete mix design advocated by the Portland Cement Association (2), modified to apply to non-plastic mixes. The writer felt that in the manufacture of concrete products a more detailed and accurate method could eventually be utilized.

With the advent of high pressure steam curing, block plants increasingly represent a sizable capital investment. It is only reasonable to suppose that manufacturers will be willing to invest additional capital for further controls if these result in a substantially more economical product.

The raw materials of the industry are cement, coarse

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[1]Numbers in parentheses refer to bibliography on Page 20.

and fine aggregate, water and, sometimes, air-entraining agents. Of these, the most costly by far is cement. If a definite saving in the quantity of cement could be effected by grading the aggregate accurately according to a predetermined pattern, the installation of screens for the separation of coarse and fine aggregate into individual sizes might well be justified. The extent of separation would be determined by economic factors.

To determine if a thorough and detailed investigation conducted at a later date might reveal information of economic value was the purpose of this preliminary study. The problem resolved itself into the following question: What effect does variation of aggregate distribution have upon the properties of the mix?

As most of the present design methods are based upon the Water-Cement Ratio and the Fineness Modulus theories, both advanced by Duff A. Abrams in 1918, (3) it was decided to make this an investigation of variations within the same fineness modulus. Zero slump was to be a limiting condition; consequently all tests were made with the maximum quantity of water consistent with this limit. Only one material was used for aggregate, but it was artificially graded to give six different gradations of the same fineness modulus. Limited time prevented this investigation from extending beyond the properties of ultimate compressive strength, absorption, and unit weight. The effects of variations in the fineness modulus of aggregate have been reported by Carl A. Menzel. (4)

CHAPTER II

INSTRUMENTATION AND EQUIPMENT

All equipment used in this investigation was that readily available in the laboratories of the Civil Engineering Department of Georgia Tech. The instruments were calibrated in either the English or the metric system making conversion of units to a common system a necessity.

Proportioning of all mixes was made by weight, all quantities being measured to the nearest one hundredth of a pound. Water was added to concrete mixes in increments of 0.11 pounds (fifty cubic centimeters).

Two sizes of molds were utilized. Fig. 1 shows the small cylinders which were made from four inch sections cut from cast iron pipe of two inch nominal diameter. Compaction in these molds was accomplished with a bullet pointed steel rod of seven-sixteenth inch diameter. The large cylinders were molded in standard six inch by twelve inch steel test molds. (5)

Dimensions of cured cylinders were taken in the following manner. Diameters were measured in three different directions at top, middle and bottom. The average area was computed using a weighted diameter found by assigning weights of one to both top and bottom average diameters, and a weight of two to the average middle diameter. The average height

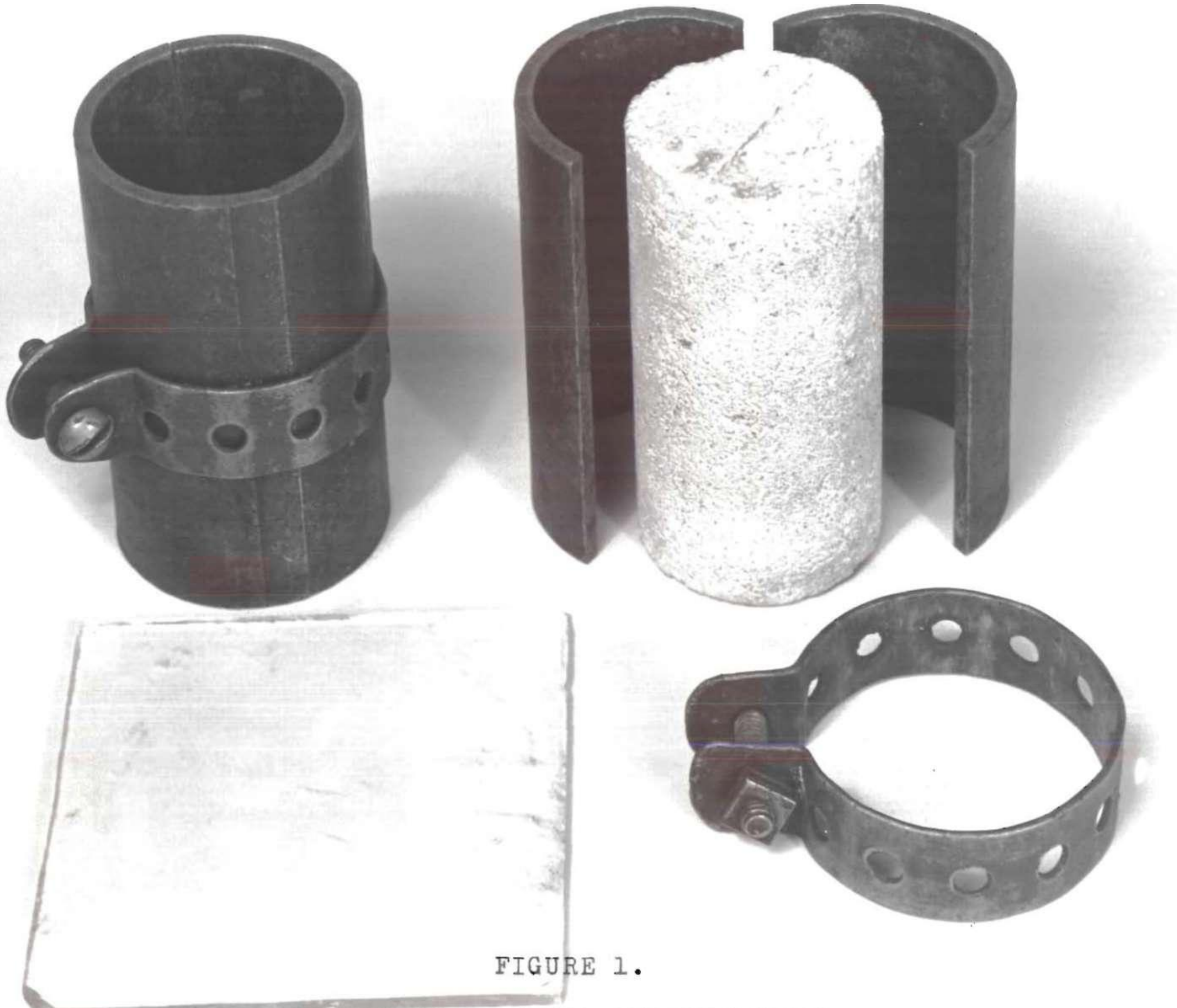

FIGURE 1.

MOLDS USED IN THE INVESTIGATION

was also determined from three separate readings. All dimensions were determined with vernier calipers to the nearest one hundredth of a centimeter (0.00394 inches). Weights of cylinders, both in the saturated and the oven dry condition, were established to the nearest tenth of a gram (0.00022 pounds).

All small cylinders were tested in compression using a Southwark Universal Hydraulic Compression machine of 60,000 pound capacity. Large cylinders were tested on a 300,000 pound capacity hydraulic compression machine reading pressures directly to the nearest twenty pounds per square inch.

CHAPTER III

PROCEDURE

The procedure followed in this investigation was divided into three definite stages: preparation of aggregate, preparation of cylinders and testing of cylinders.

Preparation of aggregate.--The crushed granite, which was to be used for both coarse and fine aggregate so as to eliminate as many variables as possible, was dried to a free flowing condition and then vibrated for fifteen minutes through a standard set of screens in a Gilson Mechanical Testing Screen machine. The aggregate was separated into the following sizes:

Passing 3/8 in. mesh -- Retained on No. 4 mesh
Passing No. 4 mesh -- Retained on No. 8 mesh
Passing No. 8 mesh -- Retained on No. 16 mesh
Passing No. 16 mesh -- Retained on No. 30 mesh
Passing No. 30 mesh -- Retained on No. 50 mesh
Passing No. 50 mesh -- Retained on No.100 mesh
Passing No. 100 mesh.

The individual sizes of aggregate were then recombined by weight according to previously determined aggregate gradations. The dry rodded unit weight of each gradation was established with a one half cubic foot measure. (6)

Next, the specific gravity, the absorption and the water content of the crushed granite were determined. (7)

An aggregate mixture composed of equal parts by weight of the three largest aggregate sizes was used in these three tests because of the extreme difficulty of determining the instant when the actual gradations used reached a saturated surface dry condition. Any errors that may have been introduced by this substitution should be negligible.

Preparation of cylinders.--From each aggregate gradation, three mixes of different aggregate-cement ratios were made. These ratios of aggregate to cement by weight were five to one, four to one, and three to one. For each mix, thirty pounds of aggregate were placed into a pan and enough water was added to bring the aggregate to a saturated surface dry condition as computed from the absorption and water content of the aggregate. The required amount of portland cement was then added and blended into the aggregate with blunted hand trowels until the mixture appeared uniform in texture and color. Water in increments of fifty cubic centimeters was then added to the mix until a distinct water web appeared when a sample of the concrete mixture was troweled.[1]

All molds had previously been well cleaned and oiled. The small molds were placed upon plate glass: the standard

[1] A water web is a system of fine lines of ridges of moisture which form in a web like manner on the surface of the concrete mix when it is troweled. For this method of determining the maximum water content to be used with zero slump concrete, the writer is indebted to several papers presented at the Quality Concrete Short Course held at the Georgia Institute of Technology, February 4-6, 1952.

cylinder upon a metal base plate. Each mold was filled with concrete in three approximately equal layers, each layer being rodded twenty-five times. The molds were then filled to overflow and the excess concrete was struck off.

After approximately twenty hours, the molds were removed and the cylinders placed into the curing room which was kept at a temperature between seventy and eighty degrees, and a relative humidity between eighty-five and ninety per cent. In addition, the small cylinders were submerged in water for the entire curing cycle.

Testing of cylinders.--After twenty-seven days, the small cylinders were taken from their water bath to be weighed and measured in the saturated condition. Then all cylinders were capped with thin layers of molding plaster and returned to the curing room.

After twenty-four hours the cylinders were tested to failure under compression. (8) Every effort was made to keep the cylinders from shattering so that they would be available for further tests.

After the plaster caps were removed, the cylinders were oven-dried to constant weight. They were then immersed in water for twenty-four hours and reweighed so that the per cent of absorption could be determined.

CHAPTER IV

DISCUSSION OF RESULTS

Six aggregate gradations, as shown in table 1, and illustrated in figures 2 and 3, were used in this investigation.

Table 1. Aggregate Gradations

Mesh size	A	B	C	D	E	F
4	16	16	8	10	12	14
8	26	16	26	16	16	16
16	6	16	16	26	16	16
30	6	16	16	16	26	16
50	26	16	16	16	16	26
100	16	16	14	12	10	8
Passing 100	4	4	4	4	4	4

All gradations have a fineness modulus of 3.36. Gradations C,D,E and F, were selected to place emphasis on progressively finer sizes. Gradation B is as uniform a mixture as is possible. Gradation A was selected as one possible extreme.

A study of figure 4 reveals that the water-cement ratio decreased as emphasis in the gradation was placed upon the finer sizes of aggregate. This means that less water is available for chemical reactions in some of the mixes, resulting in less efficient use of the cement paste, as zero slump concrete mixes always have insufficient water for complete hydration.

Figures 4, 5 and 6 all indicate that there is a definite relationship between gradation, absorption, strength and unit weight. Gradation D appears most efficient in all respects. B, the uniform gradation commonly recommended, compares favorably with C, D, E and F in most instances. Gradation A, the extreme, undoubtedly is the least efficient material used in this investigation.

Probably the most conclusive evidence that a definite variation exists is illustrated by figure 6. There the three cement ratio curves come to a peak of maximum strength at D and gradually decrease in both directions. The only value which seems to be out of line is the point on the 3:1 curve for gradation B.

In determining the absorption of cylinders as plotted in figure 7, considerable errors were introduced through the use of cracked cylinders. However, a definite pattern is apparent which should be correct relatively if not quantitatively.

Figure 8, Compressive Strength vs. Cement-Aggregate Ratio is corroboration of the commonly accepted fact that an increase in the cement-aggregate ratio causes an increase in the compressive strength. However, it must be noted that the relationship between these two factors varies considerably with different gradations.

A study and comparison of the various curves will suggest many possible relationships. Unfortunately, insufficient

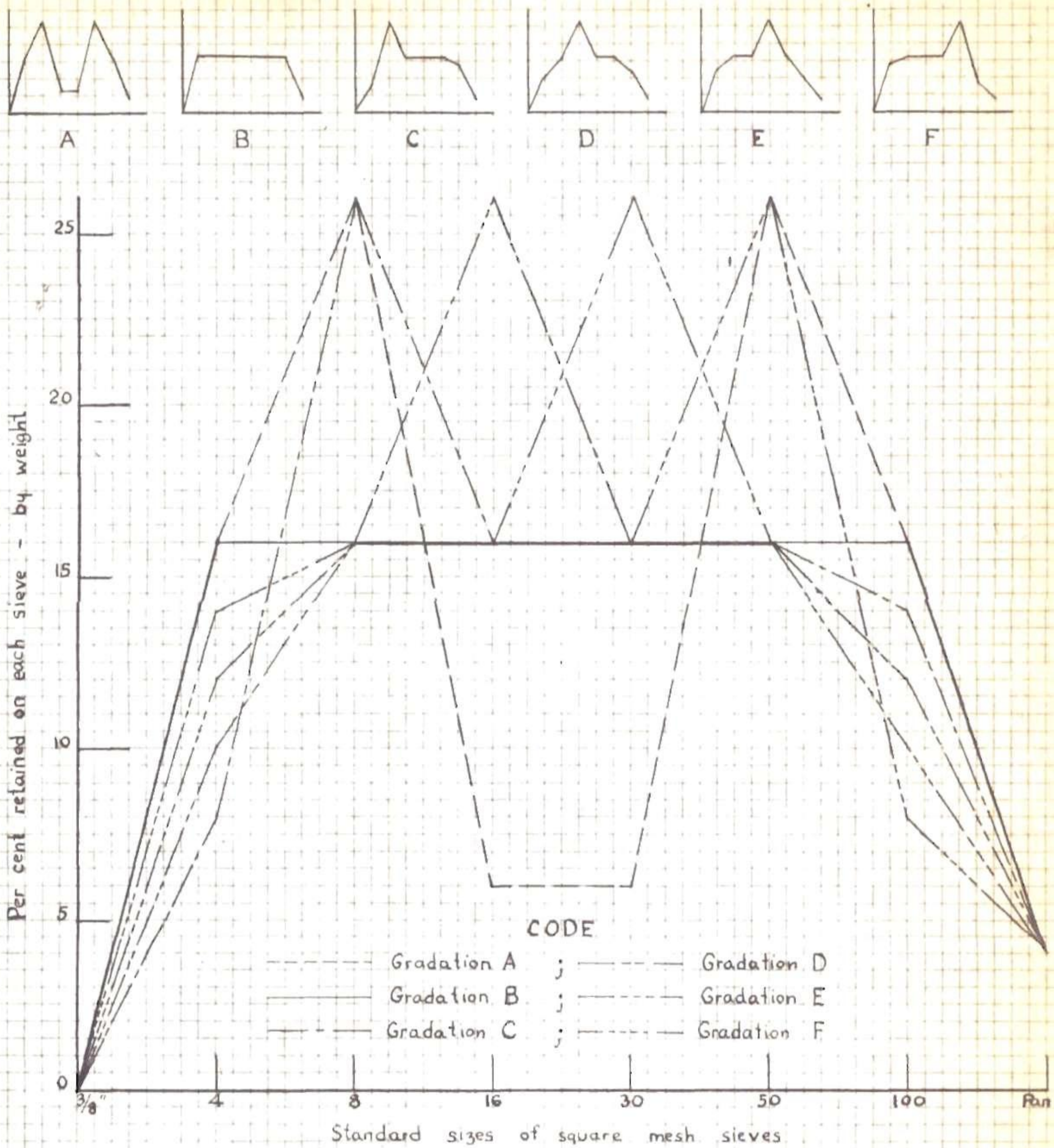

FIGURE 2.

SIEVE ANALYSIS OF INDIVIDUAL AGGREGATE GRADATIONS.

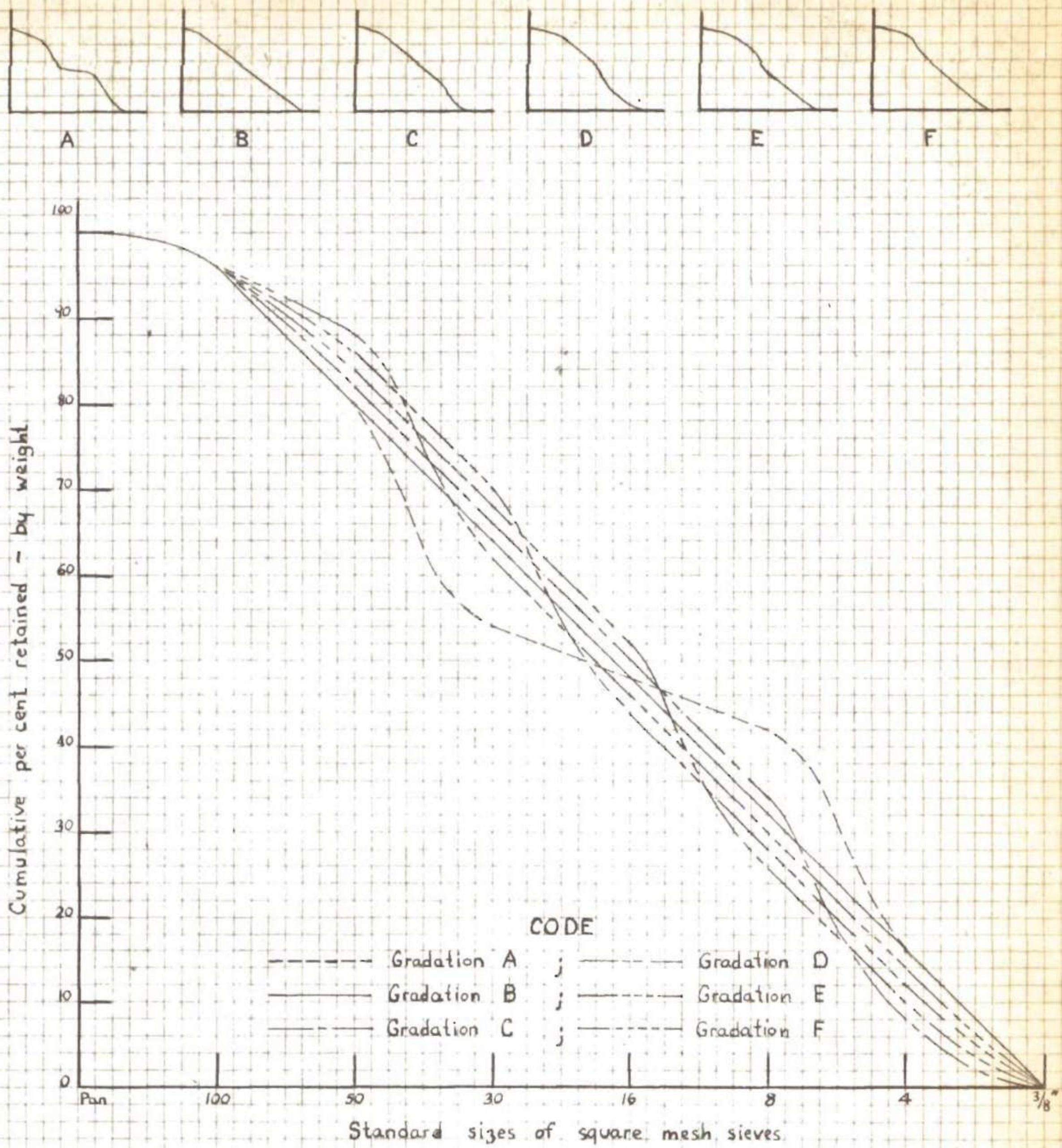

FIGURE 3.

GRAIN SIZE DISTRIBUTION CURVE
OF INDIVIDUAL AGGREGATE GRADATIONS.

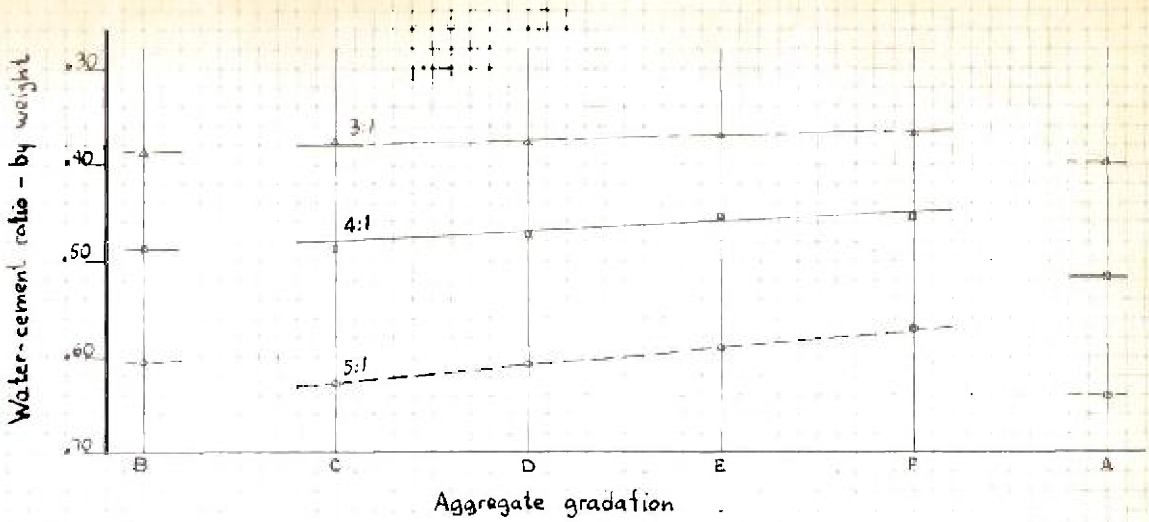

FIGURE 4.

WATER CEMENT RATIOS OF INDIVIDUAL MIXES.

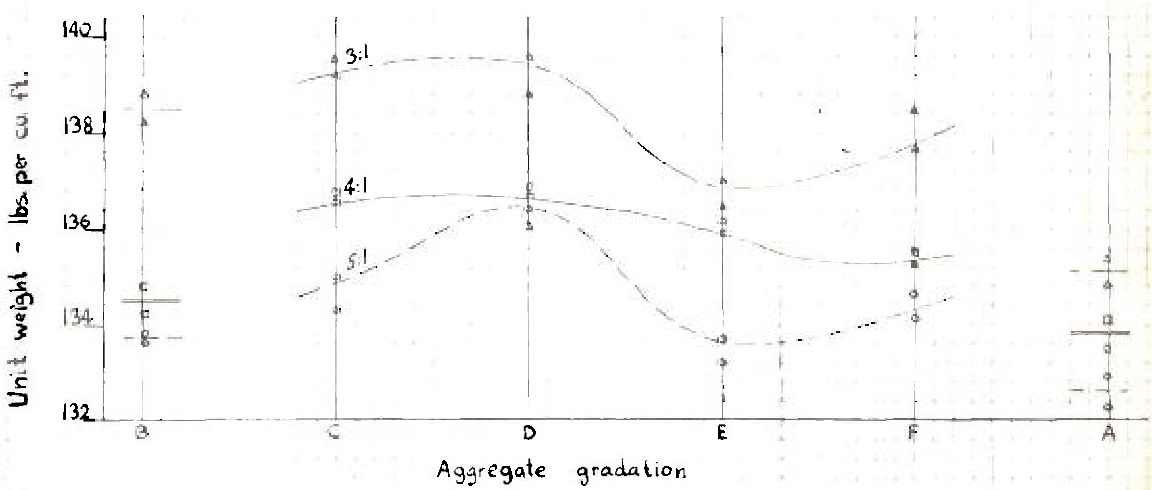

FIGURE 5.

SATURATED UNIT WEIGHT OF INDIVIDUAL MIXES.

Note: Individual curves represent the following aggregate to cement ratios by weight:
3:1 ; 4:1 ; 5:1

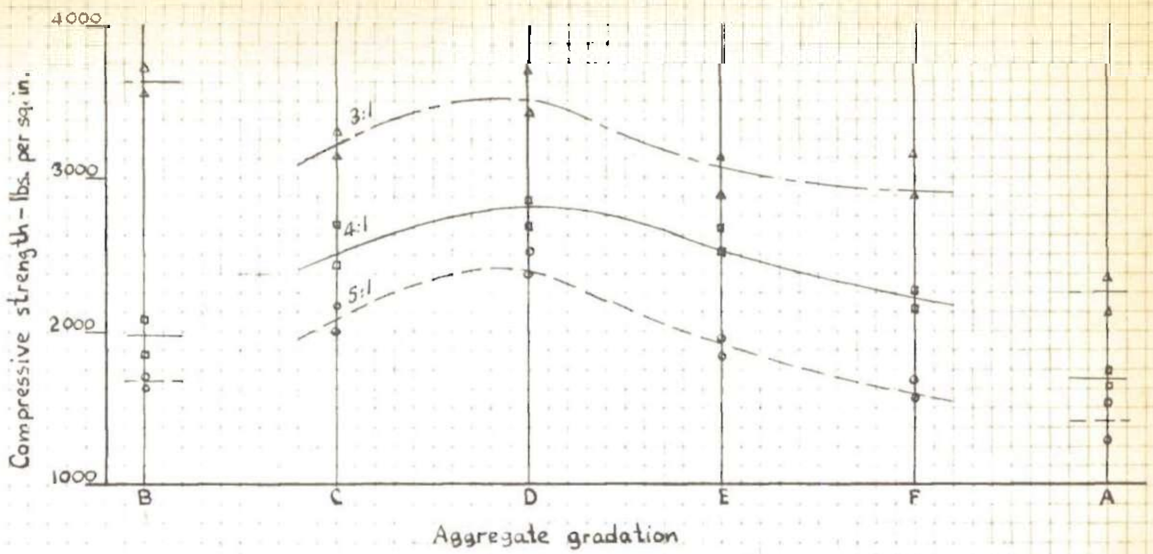

FIGURE 6.

COMPRESSIVE STRENGTH OF INDIVIDUAL MIXES.

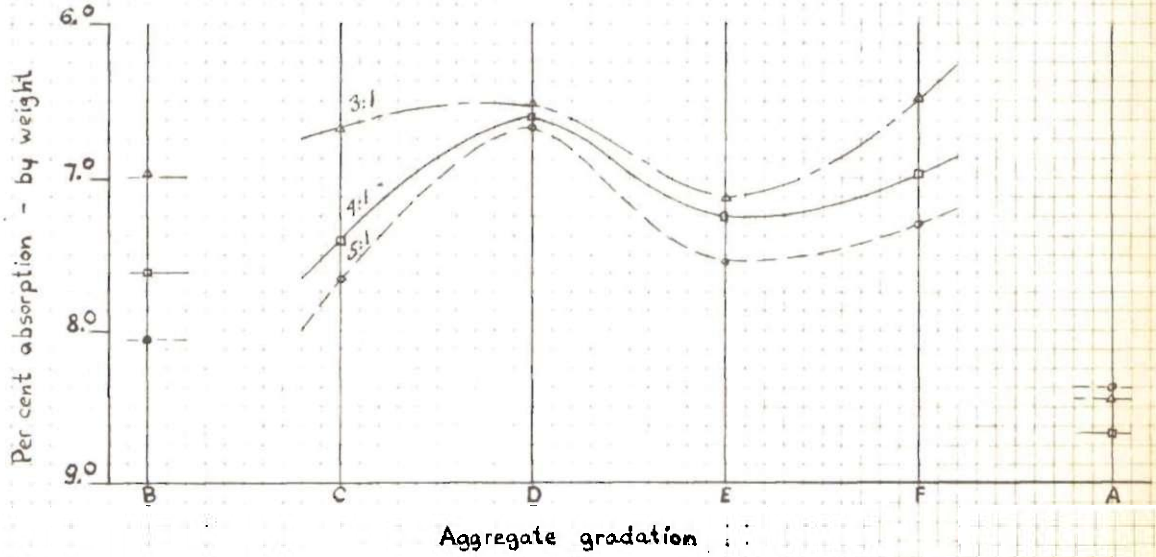

FIGURE 7.

TWENTY-FOUR HOUR ABSORPTION OF INDIVIDUAL MIXES.

Note: Individual curves represent the following aggregate to cement ratios by weight:
3:1 ; 4:1 ; 5:1

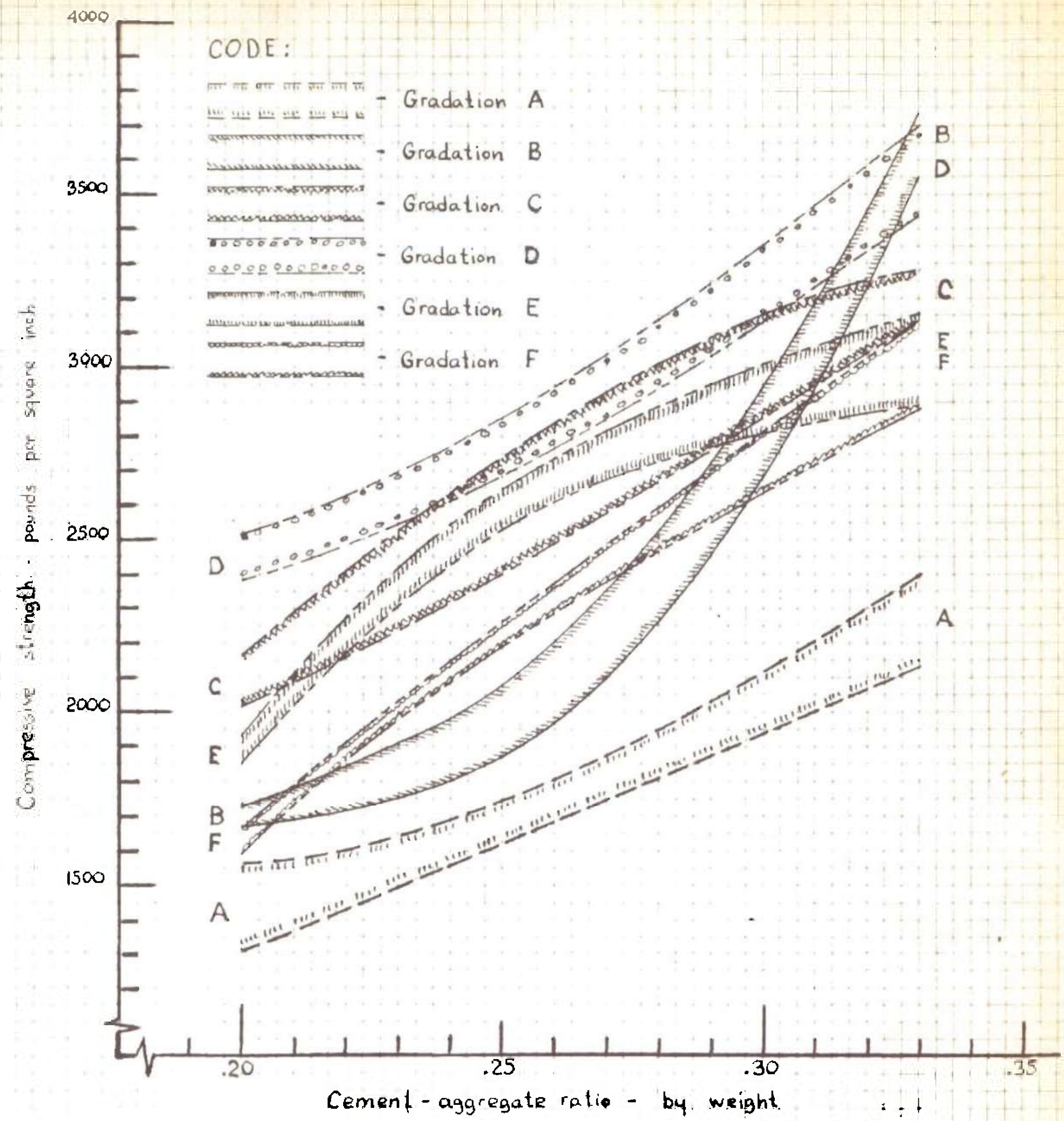

FIGURE 8.

COMPRESSIVE STRENGTH vs. CEMENT-AGGREGATE RATIO.

data has been taken in this investigation to allow for the formulation of any generalized statements.

CHAPTER V

CONCLUSIONS

As expected from the beginning, the results of this investigation did not yield sufficient information to make possible the formulation of definite conclusions about the relationships of gradation to strength and absorption. Data based upon the testing of only six different gradations can not determine the limits, nor define the relationship of an almost infinite combination of aggregate gradations.

Two positive conclusions can however be drawn from this investigation:

Variations in the gradation of aggregate do have a definite effect on the compressive strength and absorption of zero slump concrete.

Further investigation appears to be highly justified. This statement is particularly emphasized by Fig. 6, which indicates that greater strength was produced by aggregate D using a five to one aggregate-cement ratio than by aggregate A with a three to one ratio.

It appears obvious to the writer that if the trends which appear in these results are substantiated by further research, a definite theory of gradation design can be developed.

CHAPTER VI

RECOMMENDATIONS

In any further investigations, the writer would suggest the following modifications based on his own experience.

Each series of cylinders should be made with constant water-cement ratios. A separate study should be made to determine the maximum quantity of water that can be added to each mix without producing slump. In this manner, the effect of changes in the water-cement ratio would become apparent.

Every effort should be made to minimize variations that occur due to personal judgment. Compaction of greater uniformity in all cylinders could probably be obtained if the cylinders were vibrated mechanically for a definite period of time rather than rodded by hand. Refinements in procedure in general would undoubtedly result in better results and smaller possible error.

Curing conditions should be kept exactly constant. The possibilities of steam curing as a time saver should be investigated, although the saving in time may be counterbalanced by the addition of the variable factors introduced by rapid curing. Separate cylinders should be made for compression and absorption tests. Data of greater practical value may be found if cylinders were tested in a dry rather than in a saturated condition. The writer would also suggest using cylinders of three inch diameter and six inch height as specified in A.S.T.M. specifications. Larger sizes of aggregate than were used in this investigation should also be included. It may be advisable to use all aggregate in an oven dry condition to permit more accurate laboratory control.

A large number of mixes with the same fineness modulus should be prepared. When sufficient data has been collected to make a statistical analysis, other fineness moduli and other aggregates should be investigated to determine if they follow the same basic pattern.

These methods, the writer believes, will make it possible to develop a theory of aggregate gradation which, applied, will result in substantial savings in the manufacture of concrete products.

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A P P E N D I X

DESCRIPTION OF MATERIALS USED

All aggregate used in this investigation was crushed granite from the Stockbridge quarry of the Atlanta Aggregate Company. The bulk specific gravity of this aggregate was found to be 2.60; the bulk specific gravity on a saturated surface dry basis, 2.61. Absorption of aggregate was found to be 0.44 per cent. 0.07 per cent of water was absorbed at time of mixing.

The portland cement used in the investigation was Type 1 cement produced by the Penn-Dixie Cement Company.

DESIGN OF AGGREGATE GRADATIONS

A fineness modulus of 3.36 was arbitrarily selected to be used throughout this investigation.

Table 2. Aggregate Gradations.

Gradation	Mesh	Per cent retained	Per cent coarser than	Unit weight lb./cu.ft.
A	4	16	16	120
	8	26	42	
	16	6	48	
	30	6	54	
	50	26	80	
	100	16	96	
	-100	4		
		100	336	
B	4	16	16	118
	8	16	32	
	16	16	48	
	30	16	64	
	50	16	80	
	100	16	96	
	-100	4		
		100	336	
C	4	8	8	118
	8	26	34	
	16	16	50	
	30	16	66	
	50	16	82	
	100	14	96	
	-100	4		
		100	336	

Table 2. Aggregate Gradations. (continued)

Gradation	Mesh	Per cent retained	Per cent coarser than	Unit weight lb./cu.ft.
D	4	10	10	115
	8	16	26	
	16	26	52	
	30	16	48	
	50	16	84	
	100	12	96	
	-100	4		
		100	336	
E	4	12	12	114
	8	16	28	
	16	16	44	
	30	26	70	
	50	16	86	
	100	10	96	
	-100	4		
		100	336	
F	4	14	14	113
	8	16	30	
	16	16	46	
	30	16	62	
	50	26	88	
	100	8	96	
	-100	4		
		100	336	

TEST RESULTS

Table 3. Compilation of Final Data Taken for Various Mixes.

Mix no.	W/C ratio (lb/lb)	Compressive strength (psi) Upper	Mean	Lower	Unit weight (lb./cu.ft.) Upper	Mean	Lower	Ab-sorp-tion
A-5	.642	1570	1440	1310	132.9	132.6	132.3	8.38
A-4	.514	1740	1680	1620	134.1	133.8	133.5	8.68
A-3	.397	2390	2260	2130	135.4	135.1	134.8	8.40
B-5	.606	1720	1690	1660	133.8	133.7	133.6	8.05
B-4	.485	2080	1970	1860	134.8	134.5	134.2	7.62
B-3	.386	3720	3630	3530	138.8	138.5	138.2	6.91
C-5	.625	2160	2090	2020	134.9	134.6	134.3	7.66
C-4	.486	2730	2570	2410	136.7	136.6	136.5	7.39
C-3	.375	3280	3210	3140	139.5	139.4	139.3	6.65
D-5	.606	2520	2450	2380	136.8	136.6	136.4	6.68
D-4	.470	2860	2770	2680	136.7	136.4	136.1	6.61
D-3	.375	3700	3560	3420	139.6	139.2	138.8	6.52
E-5	.588	1930	1890	1850	133.6	133.4	133.2	7.55
E-4	.456	2650	2590	2530	136.1	136.0	135.9	7.27
E-3	.364	3150	3020	2890	137.0	136.7	136.4	7.12
F-5	.570	1660	1620	1580	134.6	134.4	134.2	7.29
F-4	.456	2250	2210	2170	135.5	135.4	135.3	6.95
F-3	.364	3150	3010	2870	138 5	138.1	137.7	6.43

Table 4. Test Results of Individual Cylinders.

Mix no.	Cylinder	Compressive strength (psi)	Unit weight (lb./cu.ft.)	Absorption (%)
A-5	1	1530	134.0	8.12
	2	1110	131.3	9.24
	3	1000	132.6	8.44
	4	1610	132.9	8.60
	5	1970	132.2	8.11
	L	1320		
A-4	1	1740	133.3	8.64
	2	1570	132.6	9.04
	3	1560	135.1	8.76
	4	1960	134.2	8.34
	5	1560	134.0	8.61
	L	1600		
A-3	1	2130	133.3	8.84
	2	2580	135.1	8.54
	3	2110	135.5	8.50
	4	2720	135.9	8.10
	5	1780	135.5	8.01
	L	2120		
B-5	1	1640	133.8	8.21
	2	1670	134.0	8.12
	3	1860	134.0	8.20
	4	1710	132.9	8.06
	5	1570	133.8	7.68
	L	1360		
B-4	1	1740	134.1	7.60
	2	1570	133.2	7.84
	3	2020	135.0	7.60
	4	2410	135.6	7.37
	5	2110	134.6	7.71
	L	1520		
B-3	1	3720	139.1	7.07
	2	3840	139.8	6.78
	3	3840	138.1	6.70
	4	3640	138.1	6.93
	5	3090	137.6	7.09
	L	2060		

Table 4. Test Results of Individual Cylinders. (continued)

Mix no.	Cylinder	Compressive strength (psi)	Unit weight (lb./cu.ft.)	Absorption (%)
C-5	1	2270	135.6	7.50
	2	2150	133.8	7.71
	3	2140	134.6	7.66
	4	1800	133.7	7.89
	5	----	135.1	7.56
	L	1600		
C-4	1	2480	136.2	7.54
	2	2240	136.5	7.62
	3	3020	136.9	7.07
	4	3060	136.3	7.34
	5	2050	137.2	----
	L	1580		
C-3	1	3150	139.7	6.53
	2	3090	139.8	6.60
	3	3130	139.5	6.77
	4	3560	138.9	6.66
	5	3130	139.3	6.67
	L	2180		
D-5	1	2400	137.1	6.35
	2	2190	136.9	6.52
	3	2330	136.4	6.76
	4	2750	136.9	6.98
	5	2590	135.9	6.80
	L	1920		
D-4	1	2580	138.0	6.44
	2	2530	136.1	6.83
	3	2690	135.4	6.73
	4	3000	136.0	6.58
	5	3070	136.7	6.47
	L	2120		
D-3	1	3570	139.4	7.15
	2	3710	139.1	6.50
	3	3080	138.3	6.75
	4	3200	137.7	6.83
	5	4240	141.5	5.98
	L	2400		

Table 4. Test Results of Individual Cylinders. (continued)

Mix no.	Cylinder	Compressive strength (psi)	Unit weight (lb./cu.ft.)	Absorption (%)
E-5	1	1890	132.6	7.67
	2	1860	133.1	7.55
	3	1690	134.0	7.49
	4	1930	133.8	7.71
	5	2060	133.5	7.34
	L	1600		
E-4	1	2470	135.8	7.28
	2	2390	135.9	7.49
	3	2700	135.9	7.77
	4	2870	136.9	6.57
	5	2540	135.7	7.22
	L	1960		
E-3	1	2790	136.3	7.33
	2	2840	136.2	6.92
	3	2870	135.8	7.07
	4	2770	136.7	7.25
	5	3810	138.7	7.03
	L	2360		
F-5	1	1670	134.5	6.99
	2	1420	134.0	7.43
	3	1750	135.3	6.84
	4	1590	133.6	7.51
	5	1690	134.5	7.70
	L	1400		
F-4	1	2060	135.8	6.61
	2	2300	135.4	7.04
	3	2170	135.1	7.12
	4	2340	135.3	7.03
	5	2160	135.5	6.93
	L	1560		
F-3	1	2960	137.2	6.87
	2	2730	137.3	7.42
	3	2630	137.4	6.76
	4	3830	141.2	5.64
	5	2900	137.4	6.43
	L	2120		

SAMPLE COMPUTATIONS

The following sample computations show how all the information pertaining to cylinder 1 of mix C-4 was derived from the original data.

Weight of aggregate	= 30.00 lbs.
Cement-aggregate ratio	= 1:4
Weight cement required	= 30.00 ÷ 4 = 7.50 lbs.
Water absorbed	= 0.07%
Dry weight of aggregate	= 30.00 ÷ 100.07% = 29.98 lbs.
Absorption	= 0.44%
Additional water absorbed	= 29.98 (0.0044 - 0.0007)
	= 0.11 lbs.
	$= \dfrac{0.11 \text{ lbs.} \times 28317 \text{ cc.}}{62.4 \frac{\text{lbs.}}{\text{ft.}^3} \times 1 \text{ ft.}^3}$
	= 50 cubic centimeters
Total water added	= 1700 ccs.
Water available for reactions	= 1650 ccs.
	= 3.64 lbs.
Water cement ratio W/C	= 3.64 ÷ 7.50 = 0.486

Cylinder dimensions in centimeters:

top	diameters middle	bottom	height
5.15	5.24	5.16	10.18
5.23	5.14	5.25	10.18
5.13	5.14	5.17	10.19
5.17	5.17	5.19	10.18

Weighted diameter $= \dfrac{(1x5.17)+(2x5.17)+(1x5.19)}{4} = 5.175$ cm.

Average area, A $= \dfrac{x\ 5.175 \times 5.175 \text{ cm.}^2}{4} \times \dfrac{0.155 \text{ in.}^2}{1 \text{ cm.}^2}$

$= 3.26$ in.^{2}

Volume $= 3.26 \times \dfrac{10.18 \text{ cm.}}{2.54 \frac{\text{cm.}}{\text{in.}}} = 13.07$ in.^{3}

Compressive force = 8100 lbs.

Compressive strength = 8100 ÷ 3.26 = <u>2480 psi.</u>

Weight of saturated cylinder = 467.2 gm.

Saturated unit weight $= \dfrac{467.2 \text{ gm.}}{13.07 \text{ in.}^3} \times \dfrac{1728 \text{ in.}^3}{1 \text{ ft.}^3} \times \dfrac{0.0022046 \text{ lbs.}}{1 \text{ gm.}}$

= <u>136.2 lbs. / cu. ft.</u>

Oven dry weight of sample = 262.5 gm.

Saturated weight after 24 hours = 282.3 gm.

Weight of absorbed water after 24 hours = 19.8 gm.

Per cent absorption = 19.8 ÷ 262.5 x 100% = <u>7.54%</u>

The probable error <u>E</u> of the mean of a series of <u>n</u> measures may be computed by the formula:

$$E = 0.8453 \frac{\sum_{i=1}^{n} d_i}{n \quad n-1}$$

where $\sum_{i=1}^{n} d_i$ is the sum of the deviations $d_i = (t_i - m)$, t_i being the individual measurement and <u>m</u> the mean. When <u>n</u> is equal to five, this formula becomes:

$$E = 0.0845 \sum_{i=1}^{n} d_i \qquad (9)$$

This formula was used to determine the probable upper and lower limits of the compressive strength and the unit weight of each set of cylinders.[1]

Cylinder no.	Strength	d_i(strength)	Unit weight	d_i(unit wt.)
C-4-1	2480	90	136.2	0.4
2	2240	330	136.5	0.1
3	3020	450	136.9	0.3
4	3060	490	136.3	0.3
5	2040	520	137.2	0.6
d_i :		1880		1.7
Arithmetic mean :	2570		136.6	
$E=0.0845 \sum d_i$:		160		0.1
Upper limit:	2730		136.7	
Lower limit:	2410		136.5	

[1]Because of great variations in strength, the data from "L", the 6x12 cylinders, was not included in the computation of mean values.